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Downlink Power Allocation and User Selection for CoMP-NOMA in Multi-Cell Networks

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***Abstract*— In this paper, we consider the power allocation problem in the downlink multi-cell multi-user cellular network, where the cells utilize non-orthogonal multiple access (NOMA) such that more than one user can access the same frequency-time resource simultaneously and the signals of the multi-users can be separated successfully using successive interference cancellation (SIC). We also utilize the coordinated multi-point (CoMP) transmission in which some users are located between multiple cells/ Base stations (BSs) and experience more inter-cell interference (ICI) while in non-coordinated multi-point (non-CoMP) transmission, the users experience the channel gain of one BS. In this case, we formulate the problem of maximizing the network data rate by selecting joint proper CoMP users, non-CoMP users and also downlink power allocation of non-CoMP users for each cell of the network. We propose a low-complexity iterative algorithm based on the convex optimization method and Karush–Kuhn–Tucker conditions to obtain the optimal solution of the problem. Simulation results validate the performance of our proposed algorithm for different values of the system parameters.**

Keywords*— Non-orthogonal multiple access (NOMA), coordinated multi-point (CoMP) transmission, Multi-Cell Network, Data rate of the network, Energy Efficiency.

I. Introduction

Due to the challenge of massive connectivity in fifth generation (5G) and beyond 5G cellular networks, spectral efficiency is known as one of the main goals to solve this problem. For improving the spectral efficiency, non-orthogonal multiple access (NOMA) is considered as the multiple access technology. In fact, in NOMA technology, multiple users transmit their signals on the same channel with different power levels [1], [2]. In downlink transmission under NOMA, a base station (BS) transmitter schedules multi users for utilizing the same transmission resource, then, for detecting and decoding the desired signals of multi users, the successive interference cancellation (SIC) technique is applied at the corresponding receiver [3]. In this case, resource allocation and power management of BS have been studied in NOMA based cellular networks to maximize the network data rate in downlink transmission. In [4] a power allocation problem between two users in a downlink non-orthogonal multiple access system for maximizing the sum capacity under a total power constraint and a quality-of-service condition is solved. In [5], a proportional fairness scheduling (PFS) for downlink non-orthogonal multiple access (NOMA) with two users is considered to maximize the minimum normalized rate by the power allocation approach. In [6], the power control problem for maximizing the sum effective capacity under delay quality of service (QoS) constraints is considered.

However, in a multi-cell network, co-channel downlink transmission to the cell-edge users leads to the serve interference with each other and therefore, low received signal-to-interference-plus-noise ratio (SINR) in cell-edge users. To mitigate the serve interference, a coordinated multi-point (CoMP) transmission technique is proposed in which multiple cells/BSs coordinately transmit to the cell-edge users [7]. In this paper, we use the application of CoMP in NOMA based downlink multi-cell multi-user cellular network to improve the data rate of the network. In [8], the power control problem for the downlink of a multi-cell NOMA system is considered. The goal of the problem is minimizing the total transmit power of all the base stations under the data rate requirements of the user constraints. In [9], a suboptimal scheduling strategy is proposed in mobile networks that achieves NOMA with coordinated transmitters in the downlink, with linear complexity. In [10], a multi-tier NOMA scheme is proposed for a coordinated multi-point (CoMP) network to improve the coverage of high data rate services especially when all of the users do not have the ability to receive the direct transmission from the access points. In [11], the benefit of NOMA in enhancing energy efficiency (EE) which is the ratio of the achievable sum-rate of the users to the total power consumption for a multiuser downlink transmission is investigated. The goal is maximizing EE subject to a minimum required data rate for each user. In [12], the resource allocation problem is proposed for multicarrier NOMA systems employing a full-duplex (FD) base station for serving multiple half-duplex (HD) downlink and uplink users simultaneously to maximize the weighted sum system throughput. In [13], a downlink NOMA transmission system is considered when the average channel state information (CSI) is available at the transmitter. In this paper, the optimal power allocation schemes are developed subjected to the outage probabilistic constraints and the optimal decoding order.

Although, dynamic power allocation is very important in a CoMP-NOMA system to improve performance gain; however, most of the exiting research considers the single-

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cell scenarios or multi-cell scenarios without any user selection for each cell to manage the power consumption. Consequently, in this paper, we consider user selection and dynamic power allocation problem for maximizing the network data rate in downlink CoMP-NOMA in multi-cell multi-user network under minimum rate and downlink power consumption constraints for the users in each cell.

The main contributions of this paper can be summarized as follows:

- We propose the problem of the power allocation and user selection of the cells in the downlink NOMA multi-cell multi-user cellular network which utilizes the coordinated multi-point (CoMP) transmission.
- In fact, the goal of the problem is maximizing the network data rate in a multi-cell multi-user downlink NOMA system under data rate and downlink power consumption constraints for the users in each cell by power allocation and user selection of the cells.
- We formulate the joint power and user selection optimization problem. The solution technique for this problem is also provided based on the convex optimization framework. After obtaining the optimal conditions using the Karush-Kuhn-Tucker (KKT) conditions, an iterative low complexity algorithm is proposed to find the optimal users in each cell.
- Numerical results show the effectiveness of our proposed CoMP-NOMA model in improving the network data rate and energy efficiency in comparison with the traditional CoMP-OMA systems.

The rest of the paper is organized as follows. The system model of a CoMP-NOMA-based cellular network is introduced and the optimization problem is formulated in Section II. In Section III, the optimal solution for the problem is stated. In section IV, an iterative algorithm is proposed to solve the problem. Simulation results are presented in section V, and conclusions are drawn in Section VI.

II. SYSTEM MODEL

We consider a CoMP-NOMA-based cellular network with N non-CoMP users, M CoMP users and one Base Station (BS) in each cell as it is shown in Fig.1. In each time frame, BS in i th cell, transmits informations to its destinations (users) in kth band. The total available system bandwidth is denoted by B and it is divided into K sub-channels (bands) with bandwidth B/K. It is assumed that the channel information is known perfectly. Under CoMP-NOMA model, each CoMP user receives multiple transmissions from the BSs which is belonged to them while non- CoMP users receive their signals only from the BSs which are associated them [14]. In this case, the achievable data rate for the non-CoMP-user n in kth band served by BS in ith cell is stated as

$$R_n^{i,k} = \log_2\left(1 + \frac{p_n^{i,k}|h_n^{i,k}|^2}{\sum_{n'=n+1}^{s_n^{i,k}} \rho_{n'}^{i,k} p_{n'}^{i,k}|h_{n'}^{i,k}|^2 + \sum_{i'=1,\neq i}^{I} \rho_{n'}^{i',k} p_{n'}^{i',k}|h_{n'}^{i',k}|^2 + \sigma^2}\right) \quad (1)$$

Where $p_n^{i,k}$ is the downlink transmission power for the nth non-CoMP-user in kth band from the BS in ith cell while $h_n^{i,k}$ is the channel gain between nth non-CoMP-user in kth band and corresponding BS in ith cell. It should be noted that $\rho_{n'}^{i,k}$ is the assignment index where $\rho_{n'}^{i,k} = 1$ indicates that the non-CoMP-user n is assigned to ith cell in kth band and otherwise it is zero. $\sum_{n'=n+1}^{s_n^{i,k}} \rho_{n'}^{i,k} p_{n'}^{i,k}|h_{n'}^{i,k}|^2$ shows the sum of the downlink received power for other non-CoMP-users from the BS which are in the same cell with nth non-CoMP-user but they have higher SIC ordering than user n using the NOMA technology. With SIC, the received signals of the users from BS are decoded in a decreasing order of the channel gain. $s_n^{i,k}$ is the number of the non-CoMP-users in k th band and i th cell. Also, $\sum_{i'=1,\neq i}^{I} \rho_{n'}^{i',k} p_{n'}^{i',k}|h_{n'}^{i',k}|^2$ represents the downlink received power from other non-CoMP-users in other cells with the same band which can cause severe interference to the cellular users' communications. σ^2 is the additive white Gaussian noise (AWGN) noise on kth band and ith cell. The achievable data rate for mth CoMP user can be stated as

$$R_m^{i,k} = \log_2\left(1 + \frac{\sum_{i=1}^{I} \rho_m^{i,k} p_m^{i,k}|h_m^{i,k}|^2}{\sum_{i=1}^{I} \sum_{m'=m+1}^{s_m^{i,k}} \rho_{m'}^{i,k} p_{m'}^{i,k}|h_{m'}^{i,k}|^2 + \sum_{i'=1,\neq i}^{I} \rho_{n'}^{i',k} p_{n'}^{i',k}|h_{n'}^{i',k}|^2 + \sigma^2}\right) \quad (2)$$

Where $p_m^{i,k}$ is the downlink power for the mth CoMP-user in kth band from the BS in ith cell while $h_m^{i,k}$ is the channel gain between mth CoMP-user in kth band and corresponding BS in ith cell. $\sum_{i=1}^{I} \sum_{m'=m+1}^{s_m^{i,k}} \rho_{m'}^{i,k} p_{m'}^{i,k}|h_{m'}^{i,k}|^2$ represents the interference due to other CoMP-users which have higher SIC ordering than user k according to NOMA technology. $s_m^{i,k}$ is the number of the CoMP-users in kth band and ith cell. $\sum_{i'=1,\neq i}^{I} \rho_{n'}^{i',k} p_{n'}^{i',k}|h_{n'}^{i',k}|^2$ and σ^2 are defined similar to (1). Therefore, sum data rate maximization of the problem under joint non-CoMP-user power management and user allocation can be formulated as follows

$$max_{p_n^{i,k}, \rho_n^{i,k}, \rho_m^{i,k}} \sum_{n=1}^{N} R_n^{i,k} + \sum_{m=1}^{M} R_m^{i,k} \quad (3)$$

$$\text{s.t.:} \sum_{k=1}^{K} p_n^{i,k} + p_m^{i,k} \le p_i^t \quad \forall i \in I \quad (3\text{-}1)$$

$$R_n^{i,k} \ge R_n^{th} \quad \forall n \in N \quad (3\text{-}2)$$

$$R_m^{i,k} \ge R_m^{th} \quad \forall m \in M \quad (3\text{-}3)$$

This problem is formulated for the sum data rate maximization under the joint power management for non-CoMP-users and user allocation for each band of each cell.

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(3-1) constraint shows the power budget for each cell. (3-2) and (3-3) constraints represent the individual data rate requirements for the non-CoMP-users and CoMP-users serve by BSs.

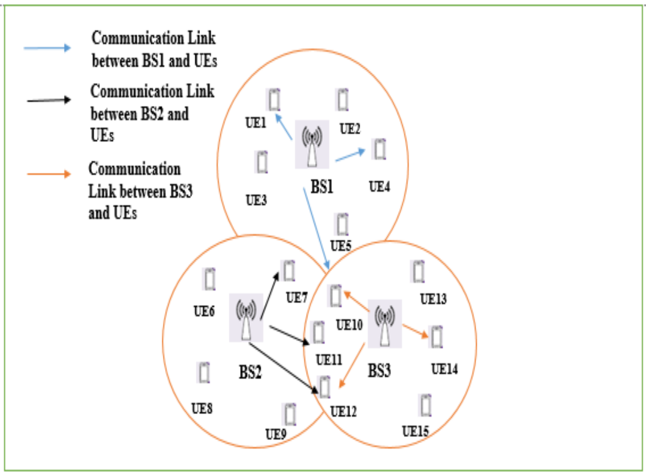

Fig. 1. An illustration of the proposed CoMP-NOMA model

III. OPTIMAL SOLUTION FOR JOINT POWER MANAGEMENT AND USER ALLOCATION

Since the problem in (3) is a convex optimization problem, we can use the Slater's theorem and Karush-Kuhn-Tucker (KKT) conditions to find the optimal solution for the problem [14],[15]. Therefore, according to the Lagrangian function, we have

$$L = -\left(\sum_{n=1}^{N} R_n^{i,k} + \sum_{m=1}^{M} R_m^{i,k}\right) + \lambda_i\left(\sum_{k=1}^{K} p_n^{i,k} + p_m^{i,k} - p_i^t\right) - \xi_n\left(R_n^{i,k} - R_n^{th}\right) - \alpha_m\left(R_m^{i,k} - R_m^{th}\right) \quad (4)$$

Where λ_n, μ_m, ξ_n and α_m are the non-zeros Lagrangian multipliers. According to the KKT conditions, the priority of users for data receiving from BS in each band of each cell is obtained as follows

$$cost(m,n,k,i) = -\left(\sum_{n=1}^{N} R_n^{i,k} + \sum_{m=1}^{M} R_m^{i,k}\right) + \lambda_i\left(\sum_{k=1}^{K} p_n^{i,k} + p_m^{i,k}\right) - \xi_n\left(R_n^{i,k}\right) - \alpha_m\left(R_m^{i,k}\right) \quad (5)$$

According to this cost function, each user which has more data rate while has less downlink power, has more opportunity to be assigned the channels of the cells. Taking deviation of (4) and using the KKT conditions, we have

$$\frac{\partial L}{\partial p_n^{i,k}} = 0 \rightarrow p_n^{i,k} = \frac{1}{|h_n^{i,k}|^2}\left[\frac{|h_n^{i,k}|^2 \xi_n}{\lambda_i} - \left(\sum_{n'=n+1}^{s_n^{i,k}} \rho_{n'}^{i,k} p_{n'}^{i,k} |h_{n'}^{i,k}|^2 + \sum_{i'=1,\neq i}^{I} \rho_{n'}^{i',k} p_{n'}^{i',k} |h_{n'}^{i',k}|^2 + \sigma^2\right)\right] \quad (6)$$

$p_m^{i,k}$ is obtained similar to (6). Complementary slackness conditions also reveal that

$$\begin{cases} \lambda_i\left(\sum_{k=1}^{K} p_n^{i,k} + p_m^{i,k} - p_i^t\right) = 0 \\ \quad \rightarrow \begin{cases} \lambda_i = 0 \;, \sum_{k=1}^{K} p_n^{i,k} + p_m^{i,k} \le p_i^t & (7-1) \\ \lambda_i \neq 0, \sum_{k=1}^{K} p_n^{i,k} + p_m^{i,k} = p_i^t & (7-2) \end{cases} \\ \xi_n\left(R_n^{i,k} - R_n^{th}\right) = 0 \\ \quad \rightarrow \begin{cases} \xi_n = 0 \;, R_n^{i,k} \ge R_n^{th} & (7-3) \\ \xi_n \neq 0, R_n^{i,k} = R_n^{th} & (7-4) \end{cases} \\ \alpha_m\left(R_m^{i,k} - R_m^{th}\right) = 0 \\ \quad \rightarrow \begin{cases} \alpha_m = 0 \;, R_m^{i,k} \ge R_m^{th} & (7-5) \\ \alpha_m \neq 0, R_m^{i,k} = R_m^{th} & (7-6) \end{cases} \end{cases}$$

According to (3), in order to maximize the achievable data rate, more number of non-CoMP users and CoMP users and also more downlink powers are required. However, (7-2) is used until the constraints (7-4) and (7-6) are satisfied. In this case, with less downlink power, the minimum data rate is obtained so that the constraints of the problem are satisfied. Therefore, (7-2), (7-4) and (7-6) are the optimal conditions.

Hence, using the sub-gradient method, the optimal values for the Lagrangian multipliers are obtained such that the multipliers are iteratively updated until convergence as follows [16]

$$\lambda_i^{t+1} = \lambda_i^{t} + \Gamma_1^t\left(\sum_{k=1}^{K} p_n^{i,k} + p_m^{i,k} - p_i^t\right) \quad (8)$$

$$\xi_n^{t+1} = \xi_n^{t} - \Gamma_2^t\left(R_n^{i,k} - R_n^{th}\right) \quad (9)$$

$$\alpha_m^{t+1} = \alpha_m^{t} - \Gamma_3^t\left(R_m^{i,k} - R_m^{th}\right) \quad (10)$$

Where t is the iteration number while Γ_i^t, i = 1,2,3 are the step sizes for Lagrangian multipliers updating.

IV. PROPOSED ALGORITHM

In order to find the optimal user allocation to each band of each cell and set their downlink power, we propose an iterative algorithm. The iterative algorithm consists of the following steps:

1) The Lagrangian multipliers are set with initial values.
2) The cost function of each user in each band of the cells is evaluated according to (5). In this case, users with higher priorities are considered for each band of the cells until the constraints of the power consumption in each cell and the minimum data rate of the users are satisfied.
3) In each iteration, for each cell, the achievable data rate and downlink power consumption of BS for data

transmission are obtained according to (3) and (3-1), respectively.

4) The values of the Lagrange multipliers are also updated using the sub-gradient method which are obtained according to (8), (9) and (10).

5) By the new value of the Lagrangian multipliers, the transmission powers of each BS to the assigned users are evaluated according to (6).

6) The algorithm comes back to the stage (2).

7) The algorithm stops iterating if the maximum number of iterations is reached. It should be noted that the value of the maximum number of iterations impacts the convergence speed of the proposed algorithm. A smaller value for the maximum number of iterations leads to faster convergence while a larger value increases the accuracy of the algorithm.

8) When the iterative algorithm terminates, the transmission power of BSs and the proper assigned users for each band of each cell are obtained. According to these, the data rate of the network is calculated according to (3).

For more illustration, the pseudo code for the proposed algorithm which is called Data Transmission Power Setting and User Allocation in Cellular Network (DTPSUACN) is shown in Fig.2.

EHDTTSCN Algorithm

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iter=500;
For $C = 1: NC$ % number of Cells
For $k = 1: K$ % number of bands
Initialization:
$\lambda_i \epsilon [\lambda_{i_{min}}, \lambda_{i_{max}}]$
$\xi_n \epsilon [\xi_{n_{min}}, \xi_{n_{max}}]$
$\alpha_m \epsilon [\alpha_{m_{min}}, \alpha_{m_{max}}]$
it=1 %%number of iterations
While (number of iterations<iter)
Determine the priority of the users for allocation in each band of each cell according to (5)
While (number of users(n)<M)
n=n+1
Compute (3-1), (3-2) and (3-3) for each band and each user, respectively
If (3-1) is satisfied, break, End
End While
update λ_i , ξ_n and α_m are updated according to (8) ,(9) and (10), respectively.
Update the downlink power of each user according to (6).
Determine the achievable data rate and downlink power consumption of the network
End While

End
End

Fig.2. Pseudo code for the proposed algorithm

V. SIMULATION RESULTS

We use MATLAB software for our simulation. In our network, non-CoMP and CoMP users are distributed uniformly in the circles with the radius 100m. Number of users is changed between 15 to 75. BS is placed in the center of the cell. Without loss of generality, number of cells is 3 and the frame duration is set to 1s. The system bandwidth is 1800 KHz while the number of sub-channels in each cell is set to 10. Every simulation result in this section is averaged over 500 realizations. We compare our proposed algorithm with other algorithms as benchmark algorithms:

- Random user selection algorithm (RUSA): In this algorithm, the non-CoMP and CoMP users are selected randomly for each cell of the network without any setting of the downlink power transmission. This algorithm is considered due to its low complexity for finding the solution.
- User Selection based on Orthogonal Multiple Access algorithm (USBOMA): This algorithm is considered to show the effectiveness of NOMA technology for data rate improvement in comparison to OMA technology.

Fig.3 shows the total data rate of the network for different number of users. According to this figure, it is clear that our proposed algorithm has the maximum total data rate of the network due to the proper selection of non-CoMP and CoMP users and setting the transmission power of BSs for each user in downlink state. USBOMA algorithm states that NOMA utilization in cellular networks improves the network data rate. It should be noted that all algorithms are compared when the constraints of the problem are satisfied. Fig.4 shows the power consumption of BS for different number of users. Although, our proposed algorithm (DTPSUACN) consumes more power than RUSA algorithm, however, due to the selection of proper non-CoMP and CoMP users and setting the transmission power of BS for each user in each cell, more data rate is obtained for our proposed algorithm. We also note that all algorithms satisfy the constraint (3-1) in the problem. Although, power control is done in USBOMA algorithm, however, due to the lack of using NOMA technology, more interference is obtained and the data rate of the network is decreased significantly. Fig.5 shows the energy efficiency of the network for different number of users. In fact, our proposed algorithm selects the proper non-CoMP and CoMP users for each cell such that the ratio of the data rate to the power consumption is maximized. Fig.6 shows the total data rate of the network for different thresholds of the power consumption for each band. According to this figure, our proposed algorithm has the maximum total data rate while USBOMA algorithm has the minimum value due to not using NOMA technology. It should be noted that the results are obtained for the first cell. Fig.7 shows the energy efficiency of the network for different thresholds of the power consumption for each band. Similar to Fig.5, it is clear that our proposed algorithm has the maximum energy efficiency while the USBOMA algorithm without any NOMA technology has the minimum value due to having more interference than DTPSUACN algorithm.

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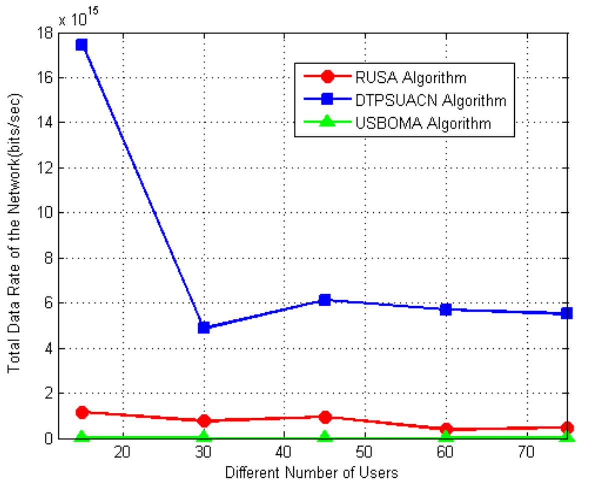

Fig.3. Total data rate of the network for different number of users

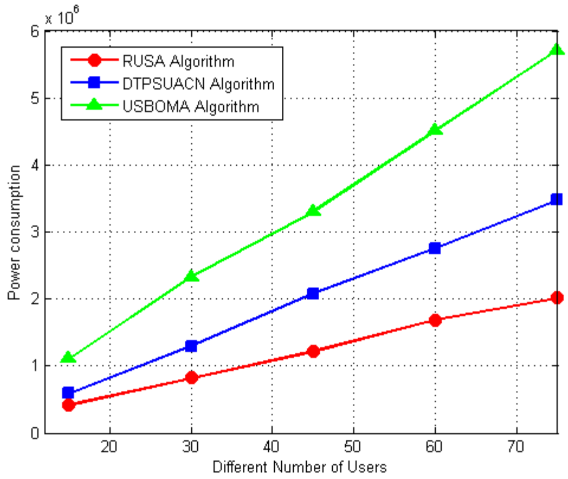

Fig.4. Power consumption for different number of users

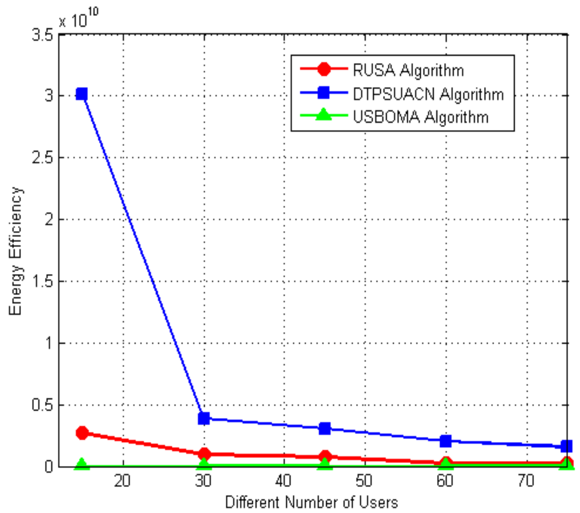

Fig.5. Energy efficiency for different number of users

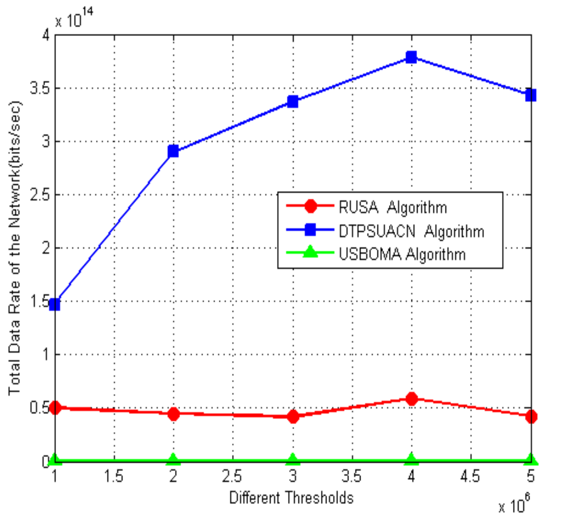

Fig.6. Total data rate of the network for different thresholds

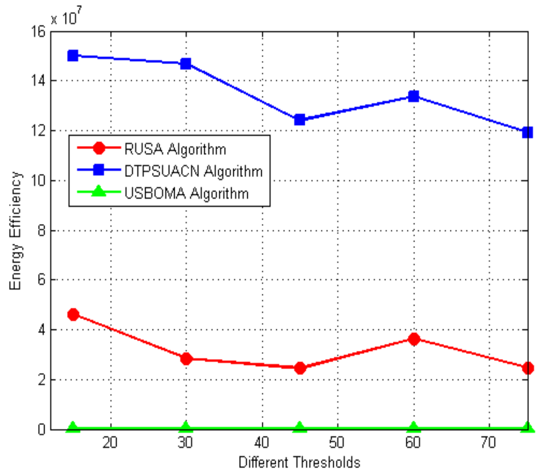

Fig.7. Energy efficiency for different thresholds

VI. CONCLUSIONS

In this paper, we proposed resource allocation and transmission power of BSs setting problem for downlink CoMP-NOMA in multi-cell networks. The goal of the corresponding problem was to maximize the energy efficiency of the user's communications with SIC consideration in each band of each cell under the constraints on the minimum required data rate of the sub-channels and power consumption of BSs in each cell. Due to the high computational complexity associated with the proposed optimization approach, we have proposed a low complexity power optimization method for each BS. For solving the problem, we applied the convex optimization method and KKT conditions to find the optimal users for each cell and control the transmission power of BSs. Simulation results show that our proposed algorithm has a better energy efficiency compared to the other algorithms due to the proper selection of non-CoMP and CoMP users and setting the transmission power of BSs in each band. Performance calculation of the proposed system model with imperfect channel state information is left for future work.

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